APPENDIX B

HAI CONSULTING, INC., "MDS/MMDS/ITFS TWO-WAY FIXED WIRELESS BROADBAND SERVICE: SPECTRUM REQUIREMENTS AND BUSINESS CASE ANALYSIS

MDS/MMDS/ITFS
Two-Way Fixed Wireless Broadband Service:
Spectrum Requirements and Business Case Analysis

HAI Consulting, Inc.

February 22, 2001

Executive Summary

MMDS/ITFS two-way fixed wireless broadband service is being deployed in a number of markets. Carriers have plans to enter and compete in many more markets. The development of these advanced fixed wireless broadband services will be stopped in its tracks under proposals by the Federal Communications Commission ("FCC") to reduce the available spectrum. Reductions in spectrum will force MMDS operators to implement more expensive network configurations or to serve fewer customers, resulting in their inability to provide service efficiently and economically.

Currently available two-way MMDS/ITFS equipment can flexibly provide broadband Internet access over a range of market sizes. Outside major population centers, a supercell system can serve an area of as much as 4000 square miles, encompassing a small-to-medium-sized town and surrounding small communities as well as relatively isolated farms and ranches. In urban areas, a system can serve a large number of subscribers in relatively small areas by reusing spectrum in a cellular architecture. A supercell MMDS/ITFS system equipped for two-way data transmission offers the most expedient and economically efficient way of providing broadband Internet access, especially in smaller markets.

The effects of a reduction in the available bandwidth can only be mitigated in one of two ways, either of which depresses the profitability of the system: constructing additional cells to reuse the remaining spectrum, or serving fewer subscribers. A business case analysis shows that a service provider can afford neither the increased investment and operating cost of the first solution, given a constant subscriber base, nor the decreased revenue that results from the second approach.

These conclusions are based on an engineering-economic model that calculates capital investment requirements, operating expenses and revenue projections relating to an MMDS/ITFS operation for a given market over a ten-year study period. Inputs and processes for the model have been developed from information provided by various MMDS/ITFS carriers, other broadband carriers, equipment manufacturers, public information, and/or other HAI sources.

Using the model, the impact on the business case for MMDS/ITFS service of removing spectrum is examined for five sample markets of varying sizes. The model very clearly demonstrates that if spectrum for an MMDS/ITFS network is reduced there is a direct, virtually linear, effect on capital requirements and operating expenses and a negative effect on the attractiveness of the business opportunity.

Moving the services to another spectrum band does not solve the problem. Among the advantages of the MMDS/ITFS band are its relative insensitivity to rain fades and superior path lengths (assuming constant antenna gains) in comparison with higher frequency bands. Another significant advantage of the current band is that it supports non-line-of-sight operation.

There are no existing frequency bands available below 3 GHz that offer sufficient capacity to accommodate current and evolving MMDS/ITFS applications. Furthermore, even if enough bandwidth were available in a contiguous band, manufacturing lead times required to redesign and produce equipment in new bands may reasonably be expected to be two to three years. Thus, if MMDS/ITFS license holders were to be required to move their services to new spectrum, commercial operations would suffer disastrous delays in equipment availability and re-licensing.

Table of Contents

MDS/MMDS/ITFS
Two-Way Fixed Wireless Broadband Service: Spectrum Requirements and Business Case Analysis

HAI Consulting, Inc.

I. INTRODUCTION

HAI Consulting, Inc. ("HAI") has prepared an engineering-economic cost model to analyze the impact caused by a reduction in the amount of spectrum currently available to MDS/MMDS operators on their business cases.[1] Based upon our analysis, we conclude that the advanced fixed wireless broadband services currently being deployed, and planned for future deployment, in markets throughout the United States will **not** be developed if the Federal Communications Commission ("FCC") were to reduce the spectrum available for these services as proposed in ET Docket No. 00-258.[2] Reductions in spectrum will force MDS/MMDS operators to implement more expensive network configurations to serve the same number of potential subscribers, or to serve fewer customers from the same capital investments. This will result in an inability to provide service efficiently and economically. In either case, their MDS/MMDS business becomes uneconomic and no longer financially viable.[3]

Section II of this paper provides a general technical description of advanced broadband MMDS networks currently being deployed and services being provided. It also provides some information regarding anticipated second generation MMDS

---

[1] A description of HAI and the principal contributors to this White Paper is included as an attachment.
[2] *See Amendment of Part 2 of the Commission's Rules to Allocate Spectrum Below 3 GHz for Mobile and Fixed Services to Support the Introduction of New Advanced Wireless Services, Including Third Generation Wireless Systems, et al., Notice of Proposed Rulemaking and Order*, FCC 00-455 (Rel. Jan. 5, 2001).

networks under development. Section III provides details and analyses regarding the relationship between MMDS system capacity and spectrum availability. The characteristics of the MMDS/ITFS frequency bands are set forth in Section IV. The business case analysis and HAI Model ("HMI") is described in Section V. It examines the market and financial implications of reducing available spectrum to MMDS operators, and sets forth detailed results of this analysis.

II. TECHNICAL ISSUES AND MMDS/ITFS

During the late 1970s through the mid 1990s, the MMDS/ITFS bands were primarily used to transmit video signals. The conversion of MMDS/ITFS spectrum to two-way broadband data use requires technology that can coexist with the continuing use of the spectrum for video services (particularly the continued use by some ITFS licensees for the point-to-multipoint transmission of video programming to ITFS receive sites). As a result, the Commission has retained the long-standing channelization plan for the bands that is based on the 6 MHz channels widely used for the transmission of composite video signals, and MMDS/ITFS broadband radio equipment is designed to operate within those standard 6 MHz channels.

A broadband data system using MMDS/ITFS spectrum requires one or more hub-like sites that contain radio equipment and antennas for transmitting data signals to subscribers and receiving signals from subscribers. The hub equipment is typically located at a commercial antenna site (often on a building top or hilltop), with the antennas mounted on a mast or tower. Depending on the size of the market to be served, a single

[3] In the remainder of the paper we will not refer to MDS and MMDS separately. MMDS should be read to include MDS.

site may suffice or multiple sites may be necessary. A later section discusses these two fundamental system architectures in more detail.

The hub locations must also combine, or multiplex, subscriber transmissions onto a common transmission system ultimately connected to an Internet service provider (ISP) as well as transmit multiplexed information generated by the ISP to the subscribers in the cell. Thus, each location must contain equipment suitable for routing subscriber transmissions in the TCP/IP format required by the ISP. Each hub site requires network management and monitoring equipment necessary to ensure reliable service and to allow the service provider to control and configure the site remotely.

Customer premises equipment ("CPE") consists of two pieces – an outdoor unit, containing a transmit/receive antenna and usually an amplifier for the received signal, and an indoor unit, containing circuitry to convert the digitally encoded radio signal to a format usable by a local personal computer or local area network ("LAN"). The CPE is designed to allow the outdoor and indoor units to be separated by a few tens of feet. A length of coaxial cable connects the units.

The CPE antenna is normally fairly "directional" and must be pointed toward the assigned hub site, and current systems require a line-of-sight path between the customer location and the hub. For this reason, the service provider uses well-trained installation personnel to handle CPE installation. There are, however, evolving technologies, discussed later in this report, that can avoid the line of sight restriction for many customer locations. This will simplify installation as well as enable the provision of service to customer locations that could not otherwise be served.

Because low CPE prices are vital for commercially successful MMDS/ITFS broadband data services, manufacturers strive for simple equipment designs in order to keep manufacturing costs as low as possible. Thus, CPE transmits at relatively low RF power levels and is generally "fixed-tuned;" *i.e.*, it is only tuned to certain transmitting and receiving channels in the MMDS/ITFS allocation. The service provider must specify the operating frequency of the CPE to the equipment vendor.

Low CPE transmitter power levels lead to the need for more robust digital modulation schemes in the upstream direction than those used by the hub sites in the downstream direction. This in turn increases the amount of upstream spectrum required.[4] In addition, changes in subscriber behavior, *e.g.*, the increasingly common practice of residential and business users of transmitting large files, further increases the requirement for upstream spectrum capacity.

III. SPECTRUM CAPACITY AND MMDS/ITFS SERVICE

Currently available two-way MMDS/ITFS equipment can flexibly provide broadband Internet access over a range of market sizes. Outside major population centers, a supercell system can serve an area of as much as 4000 square miles, encompassing a small-to-medium-sized town and surrounding small communities as well as relatively isolated farms and ranches. In urban areas, a system can serve a large

---

[4] A critical quantity in analyzing the performance of a digital radio communications system is the ratio of energy per bit to noise power spectral density, usually denoted as E_B/N_0. The higher the E_B/N_0, the lower the received error rate will be. Reducing transmitter power correspondingly reduces E_B/N_0 and thus the reliability of the received bit stream. To avoid this degradation of service quality, the system designer can reduce the distance between the CPE and the hub site, increase the transmitting antenna gain at the CPE or the receiving antenna gain at the hub receiver, or increase the energy per bit transmitted by the CPE by reducing the modulation efficiency and effectively spread the available energy over fewer bits. Shorter operating distances are clearly unacceptable, and increased antenna gain in either direction leads to unacceptably narrow antenna beamwidths.

number of subscribers in relatively small areas by reusing spectrum in a cellular architecture. A supercell MMDS/ITFS system equipped for two-way data transmission offers the most expedient and economically efficient way of providing broadband Internet access, especially in smaller markets. (A supercell is a large coverage area served by a single hub site; the coverage radius can be as large as 35 miles.[5]) A later section discusses this aspect of MMDS/ITFS technology in greater detail and explains why wireline broadband technologies are either unsuitable for or unavailable in these markets.

All presently available MMDS/ITFS spectrum is necessary for a carrier to serve markets efficiently and therefore profitably. Any significant loss of spectrum due to reallocation will reduce the single-cell capacity of a two-way system to an unacceptable level, as is discussed below. The effects of a reduction in the available bandwidth can only be mitigated in one of two ways, either of which depresses the profitability of the system: constructing additional cells to reuse the remaining spectrum, or serving fewer subscribers. As the business case analysis shows, a service provider can afford neither the increased investment and operating cost of the first solution, given a constant subscriber base, nor the decreased revenue that results from the second approach.

Based on input received from the industry, we have assumed for purposes of this analysis that 158 MHz (twenty-six 6 MHz channels plus an additional 2MHz) would be available for the provision of broadband services to consumers. Although additional spectrum is nominally allocated to the MMDS/ITFS services, in any given market some

[5] Supercell hubs are characteristically "high sites," in that their antennas are located on tall towers, hills, or buildings overlooking a coverage area. They also employ relatively high-power transmitters capable of radiating as much as two kilowatts or so over the market.

of that spectrum is likely to be unavailable to the system operator because: (i) it cannot be licensed under the Commission's interference protection rules due to the presence of a co-channel or adjacent channel stations in a nearby market; (ii) it is licensed but the licensee has chosen not to lease; (iii) it is being used to broadcast educational video programming on a point-to-multipoint basis to ITFS receive sites; (iv) it is being used to provide an education-oriented broadband service in conjunction with the operator's lease of ITFS capacity; or (v) it is being used as a guardband between upstream and downstream use. Although not all of these factors are likely to be present in every market, one or more will be present in each. The industry input received suggests that 158 MHz is a reasonable average amount of available spectrum in markets where deployment is being considered.

As the business case will demonstrate, the average available spectrum is adequate, though not optimal, to serve a reasonable subscriber population using data rates and quality of service factors that make MMDS/ITFS competitive with other broadband access providers. This service is generally comparable to service levels offered by ADSL providers and hence is the least an MMDS/ITFS provider could offer in a competitive market. Offering lower subscriber data rates to increase capacity would make the MMDS/ITFS two-way service unattractive in a competitive market and would otherwise disadvantage users in smaller markets where ADSL and other competing technologies are not available. An increase in any of these service levels will quickly reduce effective capacity.

Note that a higher degree of sectorization would produce a theoretically higher capacity. However the resulting capacity increase can only be realized if the subscriber population is more or less uniformly distributed around the transmitter site. Further, as will be discussed in a subsequent section, the implementation of reuse and sectorization techniques requires significant incremental capital investment.

MMDS/ITFS systems supporting two-way broadband data transmission can be used in a cellular configuration to increase system capacity, and such use is critical in large, densely populated urban markets. As the business case analysis shows, however, the ability to "cellularize" and implement a "multicell" system is only economically feasible when capacity is increased as a result of expanding demand. In this case, the increased network investment and corresponding costs are offset by increased revenue. Cellularization clearly involves a profound increase in system investment and is clearly not desirable as a means of mitigating the loss of network capacity that would result from reduction in spectrum in a supercell system.

It must be emphasized that, even in large markets where a cellular architecture is required to serve demand, removing spectrum from the current allocation would still have the effect of requiring service providers to subdivide cells to increase the reuse factor to allow the remaining spectrum to serve the existing market. It is also important to note that, as in any cellular system, cells cannot be subdivided indefinitely.

The radio performance of any system that reuses spectrum in a market area is limited by interference from co-channel cells, that is, cells operating on the same channels in different parts of the market coverage area. When cells are subdivided, more cells are added to the system, and the average distance between co-channel cells (the co-channel separation distance) decreases. There is a practical limit to this co-channel separation distance below which co-channel interference is likely to rise to unacceptable levels. In the case of cellularized MMDS/ITFS broadband data systems, a practical minimum cell coverage radius, as limited by co-channel separation concerns, is two miles, a value we assume in the business case analysis. The existence of a minimum cell radius, and hence coverage area, further restricts the ability of a service provider to cover the "hot spots" noted above if the current allocation is reduced. Once the minimum cell radius is reached, the only way of increasing the per-cell capacity is to increase the number of radio channels in the cell. Reducing the amount of spectrum available removes that option from the service provider.

IV. MMDS/ITFS SPECTRUM PROPERTIES

Among the critical advantages of the MMDS/ITFS band are its relative insensitivity to rain fades and superior path lengths (assuming constant antenna gains) in comparison with higher frequency bands. Systems operating at frequencies above about 3 GHz are prone to outages caused by heavy rain in certain parts of the country, and the likelihood of fading increases with the frequency. MMDS/ITFS systems thus can operate over greater ranges using antennas of reasonable gain than can systems operating at higher frequencies.

Another significant advantage of the current band is that it exhibits relatively low diffraction losses (which increase as the frequency is increased), enabling the deployment of such technologies as VOFDM (vector orthogonal frequency division multiplexing) that support non-line-of-sight operation. Such systems can greatly improve coverage by effectively removing the line-of-sight restriction from many locations in a market area, and they also facilitate user installation of customer premises equipment, which correspondingly reduces service providers' installation costs.

There are no existing frequency bands available below 3 GHz that offer sufficient capacity to accommodate current and evolving MMDS/ITFS applications. Furthermore, even if enough bandwidth were available in a contiguous band, manufacturing lead times required to redesign and produce equipment in new bands may reasonably be expected to be two to three years. Thus, if MMDS/ITFS license holders were to be required to move their services to new spectrum, commercial operations would suffer disastrous delays in equipment availability and re-licensing.

Existing radio frequency equipment designed for two-way MMDS/ITFS data transmission systems generally has been adapted from designs used in the 1850 – 1990 MHz PCS band, which helps to moderate manufacturing costs and hence equipment prices. These designs are nearly stretched to their limit at 2500 – 2690 MHz. They might be usable at 3 GHz but at increased cost. Beyond about 3 GHz, equipment designers are forced to different technologies and lower integrated circuit device densities for radio frequency parts, which profoundly increases manufacturing cost and equipment prices.[6]

V. BUSINESS CASE ANALYSIS

Removing significant spectrum from the MMDS/ITFS allocation will eliminate the viability of the business case for the fixed wireless broadband access carriers. As this section will explain and detail, the alternatives to preserve the market opportunity in the absence of adequate spectrum are expensive and not commercially viable. The carriers' only alternatives if the amount of spectrum is reduced are to deploy technology that raises

[6] See letter from California Amplifier to HAI Consulting, Inc., which details the radio equipment design issues that would be involved in shifting MMDS/ITFS to higher frequency bands. (Attachment 2)

capital requirements and operating expenses to untenable levels, or to reduce subscriber capacity. Neither alternative would leave the MMDS/ITFS carriers with a viable business.

A. Model Description

The HMI Model is an engineering-economic model that calculates capital investment requirements, operating expenses and revenue projections relating to an MMDS/ITFS operation for a given market over a ten-year study period.[7] Inputs and processes for the model have been developed from information provided by various MMDS/ITFS carriers, other broadband carriers, equipment manufacturers, public information, and/or other HAI sources. Using the model, the impact on the business case for MMDS/ITFS service of removing spectrum is examined for five sample markets of varying sizes.

Business plans for the MMDS/ITFS wireless broadband access business are being rapidly executed. This is coupled with quickly evolving technology. Each carrier has a distinct and unique market and focus, often very different from its MMDS/ITFS industry brethren. The carriers will evolve and take divergent routes depending on the particular markets they serve, their own corporate goals, and the technology choices available to them.

The model developed here does not purport to describe the operations or plans of any specific carrier. HAI constructed a generic business case based on the best available

---

[7] This model is a forward-looking incremental cost model. As such, it does not consider the effect of sunk costs such as spectrum purchases or the costs incurred to date by the carriers to develop the business. Clearly, the specific business plans being implemented by the MMDS/ITFS carriers will have included the recovery of spectrum acquisition costs.

information concerning the cost and capabilities of current and planned technology, market demand, and reasonable business practices.

MMDS/ITFS carriers have launched service in a number of markets using supercell technology. Eventually some of these markets will evolve to a multicell network configuration. However, in many of these cases, they will continue to use the original supercell. The carriers have elected to launch service to gain experience and market share, with the understanding that the technology will change.

In the face of a nascent technology path, the HMI model makes a strictly binary selection of either supercell or multicell technology, which is a simplification of the network decisions carriers will face. The methods, means and permutations that the evolution from supercell to multicell can take are virtually infinite, and therefore highly complex to model and explain.

Fortunately it is not necessary to model the supercell to multicell evolutionary process to explain the need for adequate spectrum. The experience of other wireless carriers demonstrates the absolute need for spectrum to manage the process of moving from an early technology (for instance analog cellular) to the next generation (digital cellular). The ability to serve a market with a supercell is not only economically efficient, as the business case will demonstrate, but the broad coverage pattern includes many users in low-density areas not otherwise served by broadband access providers. Although the model makes a strict binary selection of supercell or cellular technology, in practice some operators will maintain a supercell utilizing some channels to assure broad geographic coverage, while cellularizing other channels to maximize spectrum reuse.

MMDS/ITFS services and networks may evolve in various ways. The HMI Model demonstrates the effect of losing spectrum in any MMDS/ITFS network technology environment by constructing a pair of straightforward business case scenarios. These scenarios produce financial results by measuring the impact on capital requirements, operating expenses, and the overall business proposition of two alternative spectrum availability assumptions.

The first scenario produces model results with the carrier using 26 channels, which, as discussed above, is a reasonable assumption for the number of usable channels available to MMDS/ITFS carriers within a market. With the exception of changing the amount of available spectrum, the second scenario uses all the same inputs for technology, operating and market inputs and costs. For the second scenario, the available spectrum is reduced by 15 channels (90 MHz) to 11 channels. As will be shown, the resulting impact on the business case is negative and significant. In short, the investment is no longer viable.

For purposes of this study we have elected to employ a generic subscriber profile. The projected subscriber base will be a mix of residential and commercial subscribers, reflecting the ability of MMDS/ITFS to meet the needs of both market segments.[8] There are a wide range of potential service plans that an MMDS/ITFS carrier could offer, with varying data speeds and pricing. For the sake of keeping the results to the point and

[8] This varies from most of the other broadband wireless competitors such as Teligent (using DEMS at 24 GHz,), XO (an LMDS carrier at 28-30 GHz) and Winstar (employing 38-39 GHz frequencies) who all have a business–centric customer focus. This is largely the result of the cost of the technology they must use, which is driven by the spectrum they hold.

understandable, only two broadband data service plans are included in the model, one each for residential and commercial subscribers.[9]

B. Major Model Cost Drivers and Inputs

The key drivers for model results are investment costs, market size as measured by households ("HHs") in the sample service areas; 10th year subscriber penetration targets (which is the demand function); subscriber service levels and pricing; and the amount of spectrum available to the MMDS/ITFS network for that market. As noted above, a change in the amount of spectrum is the key input to be studied. This will be varied by 90 MHz, a figure derived from the FCC's Interim Report.[10] Setting the penetration targets drives subscribership and capacity requirements, which in turn generates investment requirements and operating expenses.

Service Areas

In order to capture the effect of spectrum reduction on a variety of market types, markets as represented by Basic Trading Areas ("BTAs") have been divided into five equal groups, or "quintiles", based on population.[11] Each quintile has been analyzed to determine the range of population in the constituent BTAs, both in terms of people and

---

[9] Voice service has not been included in the HMI Model. Although all the MMDS/ITFS carriers have indicated they eventually plan to include it in their service offerings, at this point the voice technology is yet to be clearly defined and priced. The quality of service requirements for competitive voice service will undoubtedly require incremental bandwidth within the network, no matter the ultimate technology solution.

[10] Interim Report, Spectrum Study of the 2500-2690 MHz Band, The Potential for Accommodating Third Generation Mobile Systems. Federal Communications Commission Staff Report Issued by: Office of Engineering and Technology, Mass Media Bureau, Wireless Telecommunications Bureau, International Bureau, November 15, 2000, p 37.

[11] The FCC has used a number of different market definitions for spectrum auctions. MDS/MMDS authorizations were sold in Auction #6, which ended in March 1996. For this auction the FCC chose to use Basic Trading Areas as defined by Rand McNally. Rand McNally defined 487 BTAs in the *1992 Commercial Atlas & Marketing Guide* and the FCC added six BTA-like geographic areas, bringing the total to 493 markets auctioned. BTAs differ from Metropolitan Statistical Areas (MSAs) in that they include surrounding low-density areas, and ultimately every county in the United States is included in a

households, and the median market size has also been determined. A BTA can encompass a significant amount of unpopulated or nearly unpopulated territory. Therefore, a second analysis was performed using BTAs containing Statistical Metropolitan Standard Areas to determine national average concentration factor for population within BTAs. It was determined that on average 83.3 percent of the population within a BTA is clustered in a single metropolitan area, which would be the most likely area for an MMDS/ITFS carrier (or any broadband carrier for that matter) to serve. This factor was applied to the median market for each quintile to produce a sample market size, quantified by population and households, to be used in producing model results.

Tables V-1a and V-1b provide information on the market sizes for each quintile. The quintiles are presented both in terms of population ("POPs") and HHs.[12] Population is more generally used and understood so it is provided for reference purposes. However, the model is structured based on household penetration (since residential service is generally sold to a household not an individual) so the ranges are also presented on the basis of HHs. The column "Quintile Sample Market Pops" in Table V-1b presents the number of HHs that are the sample market sizes to be analyzed using the model.

BTA. In contrast, MSAs only include more densely populated counties containing, or near, cities with 100,000 or more residents.

[12] There are on average 2.62 POPs per HH.

Table V-1a: Quintile Ranges Based On BTA Population, Expressed in POPs

Quintile	Maximum Market Size In Quintile Range	Minimum Market Size In Quintile Range	Median Market Size In Quintile Range	Adjustment For Population Clustering In BTAs	Quintile Sample Market Pops	# Of BTAs In Quintile
1	18,750,000	585,801	1,217,900	0.833	1,014,511	99
2	585,800	251,401	354,100	0.833	294,965	99
3	251,400	160,301	208,800	0.833	173,930	98
4	160,300	100,101	126,300	0.833	105,208	99
5	100,100	1	72,650	0.833	60,517	98

Table V-1b: Quintile Ranges Based On BTA Population, Expressed in Households

Quintile	Maximum Market Size In Quintile Range	Minimum Market Size In Quintile Range	Median Market Size In Quintile Range	Adjustment For Population Clustering In BTAs	Quintile Sample Market HHs[13]	# Of BTAs In Quintile
1	7,156,489	223,589	464,847	0.833	387,218	99
2	223,588	95,955	135,153	0.833	112,582	99
3	95,954	61,184	79,695	0.833	66,386	98
4	61,183	38,207	48,206	0.833	40,156	99
5	38,206	1	27,729	0.833	23,098	98

Service Configurations and Demand

The demand parameters are the first significant inputs to the model. They are based on projected subscriber penetration levels for a particular market at the tenth year. Table V-2 shows the demand parameters by quintile, as defined by residential penetration

[13] The model includes a population growth factor based on the average projected annual growth (2000 – 2010) for the United States, which is 0.08%. U.S. Census Bureau, Statistical Abstract of the United States: 1999, (119th edition) Washington, D.C. 1999; Table 4, p.9. Thus by year ten the model is basing penetration on household counts roughly 7.4% higher than the first year numbers shown in this table (the growth is accrued at the end of each year for the following year, so there is no growth included for year ten).

percentage into the sample market HHs. Business penetration is set as a percentage of residential subscribers.[14]

Table V-2: HMI Model Penetration Targets by Quintile

Quintile	Target HH Penetration For Year 10	Business Subscribers as a % of Residential Subscribers
1	8.0%	11.0%
2	8.5%	11.0%
3	9.0%	11.0%
4	10.0%	11.0%
5	11.0%	11.0%

Overall, the Target HH Penetration levels are consistent with a number of industry projections, both provided by the carriers and from outside sources.[15] The penetration inputs ramp up inversely to market size, with the smaller markets showing 37.5 percent more relative penetration than the largest. Early experience from the MMDS/ITFS carriers indicates, as would be expected, that in areas where they face little or no competition from cable modem and/or DSL service, they do achieve a higher penetration level.[16]

The model provides for a single residential and a single commercial service. Service is broadband data only, and the data-speeds, activity factors and pricing are as defined in Table V-3. Some of the MMDS/ITFS carriers will provide guaranteed service

---

[14] That the model is driven by residential penetration is based on two factors. First, as noted previously, MMDS/ITFS is unlike most other wireless broadband access services in that it has residential offerings (see http://www.sprintbroadband.com/availability/residential.pl). Second, there is readily available public data concerning households allowing for standardized market definitions.

[15] See for instance http://www.emarketer.com/analysis/broadband/20010205_broadband.html, which projects penetration of non-DSL and cable modem broadband access service among all broadband households growing from 0 percent to 14.6 percent between 2000 and 2004, which projects to 30 percent after ten years. Most of this is attributed to MMDS/ITFS and some to other fixed wireless. At that point 30 percent of broadband households would equal roughly 8 to 10 percent of all households.

[16] This is not to imply that the target penetration numbers can be achieved for any market without significant effort, proper management and diligent execution of well-conceived business plans. The MMDS/ITFS carriers clearly recognize they are in a competitive market and are positioning their offerings and organizations to meet the competition.

levels to their business customers. Competition from DSL and cable modem service will likely require MMDS/ITFS carriers to increase subscriber data rates in order to maintain revenue levels. Residential broadband service subscribers are likely to be relatively intensive users of Internet service. As high bit-rate services, including video applications, continue to evolve, this intensity will increase. Moreover, as telecommuting and home offices proliferate, residential broadband demand will increase. Therefore, the model is engineered to accommodate these expected increasing service demands by modeling data rates at the high end of those offered by current competitive services and by providing sufficient peak capacity to handle the intensive use.

Table V-3: HMI Model Subscriber Service Parameters

Service Type	Down-stream Kbps	Up-stream Kbps	Down-stream Activity Factor	Up-stream Activity Factor	Monthly Broadband Service Price
Residential	512	256	.05	.05	$49.95
Commercial	1,024	512	.25	.25	$399.95

Note that the commercial service has both higher data rates and activity factors.[17] The former anticipates that a commercial service will likely be serving a LAN with multiple users and the latter anticipates those users will be more active. Together, they represent a competitive and markedly higher quality of service provided to commercial subscribers, which is reflected in the pricing. Both commercial and residential services include Internet access, so there is no additional ISP charge as is often found with ILEC DSL service.

[17] The activity factor is the fraction of time that a user terminal actively transmits and receives in an overall busy interval.

Investment and Capacity

As noted above, the model assumes two fundamental MMDS/ITFS network structures. Smaller markets are served with a single central site, or hub (called the "supercell" configuration). Larger markets are served with multiple sites (referred to as the "multicell" architecture), which reuse the available spectrum among the cell sites.

There are three versions of the supercell case: omni-directional transmission in the downstream and upstream directions,[18] upstream (fixed site receive coverage) sectorization using four sectors, and upstream sectorization with ten sectors. In the latter two cases, the downstream transmission remains omni-directional.[19] Sectorizing in the upstream direction allows the system operator to reuse the radio channels assigned for upstream transmission within the supercell.

The model assumes that upstream channels will be reused in alternating sectors. In the four-sector case, this assumption allows each upstream channel to be used twice in the supercell, thus doubling the effective upstream capacity. In the ten-sector case, each upstream channel is used five times, increasing the upstream capacity by a factor of five compared with the upstream omni-directional case. Table V-4 contains the fixed site investment (before radios are added) for the three supercell cases and Figure V-1 shows the antenna sectorization plan for the two supercell sectorization cases.

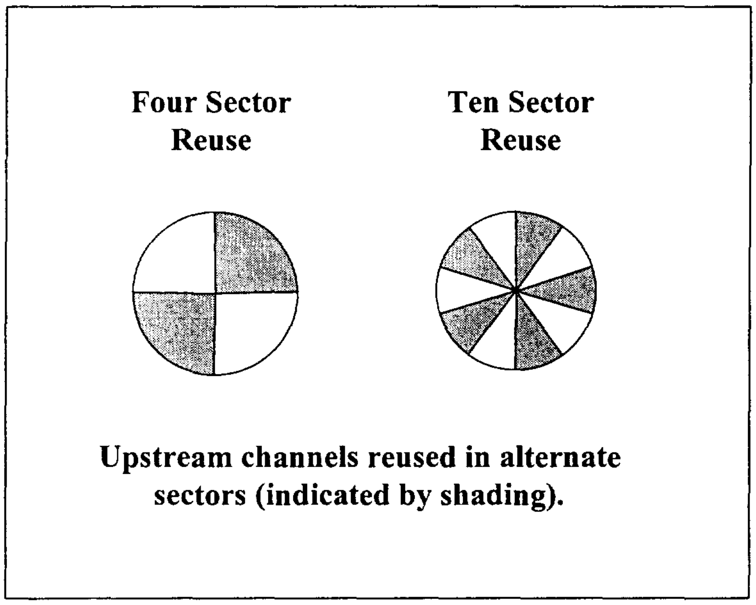
---

[18] In this description, the downstream transmission is from the hub site to the subscribers, and the upstream direction is defined as being from the subscribers to the hub site.
[19] MMDS/ITFS service providers are finding that their systems tend to be dominated by upstream traffic, owing at least in part to increasing upload file sizes by residential users as well as the need for less-efficient radio modulation techniques in the upstream direction, as is discussed elsewhere in this document.

Table V-4 Fixed Site Investment

Upstream sectorization	Fixed investment (no radios)
Omni-directional	$ 700,000
Four (90°) sectors	$1,100,000
Ten (36°) sectors	$1,700,000

Figure V-1 Antenna Sectorization Plan



The supercell fixed investments include towers, antennas, transmission lines (cables), transmitter combiners (to allow sharing of antennas by multiple transmitters), receive multicouplers (to allow sharing of antennas by multiple receivers), duplexers (to allow simultaneous use of antennas by transmitters and receivers), backup power, network management and monitoring equipment, and IP switching/routing. The increase in investment shown for the four- and ten-sector cases reflects the fact that additional antennas, duplexers, transmission line, combiners, and multicouplers are required for the additional sectors.

The model also assumes a dedicated microwave system between the hub site and the local telephone company ("ILEC"), with an initial investment of $145,000 for a DS-3 system with hot-standby redundancy. The model will add to the initial investment

$25,000 per additional DS-3 radio as required by modeled subscriber demand. It further assumes a leased connection from the ILEC to the ISP at $20,000 per month per OC-3.

The MMDS/ITFS radios for the supercell case are assumed to be equipped as 6 MHz radios configured in 2 MHz "segments," with an initial investment of $40,000 for the first 2 MHz equipped per 6 MHz channel and an incremental investment of $17,500 for each of the two additional 2 MHz segments per 6 MHz channel. This growth scheme is characteristic of currently deployed MMDS/ITFS equipment.

In the multicell configuration, the model assumes three sectors per cell, with a three-cell reuse plan (*i.e.*, all the available spectrum is used in a cluster of three cells, and the cluster configuration is replicated over the market area to serve the subscriber demand).[20] This is characteristic of all cellular-like systems that reuse spectrum across a market area. The sectorization in this case is required to reduce interference between co-channel cells in the coverage area, a practice that also is typical of cellular architectures.

The model assumes a fixed investment per multicell site of $850,000 for towers, antennas, transmission lines, combiners, multi-couplers, duplexers, backup power, network management and monitoring equipment, and fixed investment for the radio system. There is another $150,000 per market included in the model for IP switching/routing for the multicell case.

Multicell MMDS/ITFS radios are assumed to exhibit the same growth increments as the supercell MMDS/ITFS radios. The investment assumptions are $40,000 for the first 2 MHz of a 6 MHz channel, and $10,000 for each of the second and third 2 MHz

[20] The three-cell reuse plan with three sectors per cell is one of a number of possible cellularization schemes. A four-cell, four-sector-per-cell plan, another common reuse and sectorization scheme, could